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Evaluation of the Taxonomic Consistency of Ontologies based on WordNet Hierarchical and Lexical Relations

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Abstract

Presently, a considerable number of knowledge engineering researches have focused on the automatic building of ontologies. However, the uncertainty of the techniques and eventual heuristics adopted during the construction process has led researchers to explore methods for verifying and improving the quality of the outputs. In this intention, we propose a vision for checking the hierarchical structure of ontologies based on the WordNet lexical database as a background knowledge source. In order to test our work, we try to apply our proposed method on an existing valid geographic objects ontology.

Keywords: *geographic objects, knowledge modeling, ontology building, Taxonomic structure, similarity measures, evaluation, quality.*

1 Introduction

Satellite imagery is a relevant source of information for the identification of objects that make up the surface of the earth. Their exploitation in a spatio-temporal context helps to monitor and predict their behavior over time and to take appropriate decisions for the management of the environment.

Indeed, the advent of high-resolution images enabled the development of an object-oriented approach where the analysis of a scene is attached to groups of pixels representing concrete objects having a specific semantic. However, this progress leads to a large amount of available information that cannot be processed in its entirety by domain experts. This motivated the interest of research on the full or partial automation of the process of knowledge representation and extraction applied to satellite imagery. To use geographic image databases, the researchers used several knowledge representation formalisms, in particular the ontologies.

Nowadays, ontologies are becoming very popular in the area of knowledge management and sharing, especially after the evolution of the Semantic Web. They are considered as one of the most powerful tools for knowledge representation and reasoning. They aim to provide a commonly accepted understanding of a specific domain through the generic modeling, the exchange and the sharing of its specific knowledge. Knowledge is modeled in the form of concepts and their relations to each other. Several studies were interested in the use of standardized ontologies to share and annotate satellite image information [7, 1, 8, 4, 26, 20, 31]. The majority of these works presupposes the existence of a domain ontologies that may be developed, or be carried out, within the target application [4]. However, few studies have focused on their evaluation or validation.

In fact, the quality of an ontology is too sensitive to many parameters such as the consistency of the semantic resources from which it is built and the used techniques and heuristics to extract and organize relevant knowledge [19]. Therefore, as all engineering artifacts, assessing the quality of ontologies still remains an important issue for ontology engineering. The evaluation covers the structure and the content of ontologies and allows to verify several related criteria such as their consistency and their adequacy to the user's requirements and pre-established constraints.

In this paper, our main research question is how to examine taxonomic structure of a given geographic objects ontology. Firstly, we summarize the main evaluation alternatives. Secondly, we expose our method and the related structural measure for verifying the ontology hierarchical structure based on the WordNet[1] lexical database. Thirdly, we reserve the last section to an experimental study in which we expose and interpret the results of the application of our proposal on a geographic objects ontology.

[1] https://wordnet.princeton.edu/

2 Ontology evaluation: State of the art

Evaluation is a crucial phase in the building process of ontologies. It helps to simplify their development, to ensure their relevance to the requirement of a particular domain and to detect eventual ontology changes. However, the lack of unifying framework for methods and metrics for evaluating ontologies have led to several trials, each of which defines its own method and set of metrics. In this section, we try to summarize the main evaluation methods that can be classified according to their purpose into three categories: ranking, correctness, or quality.

When trying to reuse the already existing onotologies for a particular study domain, we are faced with the problem of determining the suitable ones for our needs. In this context [17] have presented an approach for clustering ontology. The main goal of this approach is to use a set of similarity measures for comparing ontology-based meta-data. Based on this work, [27] have developed the OntoQA approach that analyzes ontology schemas and their populations and describes them through a well defined set of schema and meta-data metrics. The first group includes the diagram metrics of ontologies, whose intention is to evaluate the ontology design and its potential for knowledge representation. The second group is interested in evaluating the structure of the knowledge base and more specifically how data is placed in ontology.

Further, the ranking category includes approaches for ranking and selecting ontologies. These approaches allow ranking a set of candidate ontologies in order to choose the most appropriate for a particular task. Ontometric [15] is one of the main used methods for systematic ontology selection, it aims to suggest the best ontology for a particular project on the basis of 160 properties organized in five dimensions of quantitative measurements: content, language, methodology, tool and costs. [21], have provided a corpus-based method to evaluate the functional adequacy of ontologies. [22] have proposed an ontology selection and ranking model consisting of selection standards and metrics based on better semantic matching capabilities. The proposed model allows to enhance the ontology selection and ranking method practically and effectively by enabling semantic matching of taxonomy or relational linkage between concepts and to identify what measures should be used to rank ontologies in a given context and what weight should be assigned to each selection measure. FOEval [3] is another model which presents two main features: first, it enables users to select from a set of proposed metrics, those which they help in the ontology evaluation process; and to assign weights to each one based on assumed impacts on this process. Second, it enables users to evaluate locally stored ontologies, and/or request search engines for available ontologies. The main goal of this model is to ease the ontology evaluation task, for users wishing to reuse available ontologies, enabling them to choose the most adequate ontology to their requirements. To evaluate and rank candidate ontologies, FOEval use a set of metrics that include: coverage, richness, detail-level, comprehensiveness, connectedness and computational efficiency.

The correctness category includes the approaches accounting for the formal correctness of the ontological knowledge and used primitives. In this category, the best known approach is Ontoclean [12] which is designed in order to justify the kinds of decisions that experienced ontology builders make and to explain the common mistakes of the inexperienced, as it analyses the intentional content of concepts. It is based on principles of rigidity, identity, unity and dependence. Based on this method, [5] have developed a framework which looks for taxonomic aspects such as circularity and redundancy, as well as errors in disjoint groups. [28] have developed another tool for evaluating real-world ontologies. [30] have proposed a tool that evaluates correctness, where an internal evaluation is performed, based on the correct usage of OWL primitives.

The third category addresses the evaluation of the global quality of ontology. Following this approach, the EvaLexon method [25] aims to evaluate the ontologies during their development from texts. It measures the most appropriate terms in ontology. The relevance of a term is judged by its frequency in the text from which the ontology was built and the list of terms for a specific domain. The evaluation is based on four metrics: precision, recall, coverage and accuracy. In turn, [9] have approached the ontology evaluation as a diagnostic task based on ontology descriptions, using three categories of criteria: structural (depth, breadth, tangledness, dispersion, consistency, anonymous classes, cycles, and density), functional (competence adequacy, functional modularity, precision, recall and accuracy), and usability profiling (documentation, efficiency, interfacing). By combining the different measurable criteria for each category, nine quality principles (qoods) are defined: cognitive ergonomics, transparency, integrity and computational efficiency, meta-level integrity, flexibility, expertise compliance, conformity with extension, integration and adaptation procedures, generic access and organizational ability.

To assess the quality of evolving ontologies, [16] have proposed a set of cohesion metrics that are considered as stable, where their results do not depend on

the semantic or structural ontology representation. In the same way, [6] proposed the Onto-Evoal approach which is based on an evaluation model to guide the management of inconsistencies by assessing the impact of proposed resolutions on the content and use of the ontology. This model defines a set of quantitative metrics allowing choosing a resolution that preserves the quality of the evolved ontology. Quality criteria considered in the proposed approach are: complexity, cohesion, taxonomy, abstraction, modularity, completeness and understanding. By referring to the work of [10] and [11], [29] presents a theoretical framework for assessing the quality of an ontology for the Web. The framework summarizes ontology evaluation methods in two dimensions: ontology quality criteria (accuracy, adaptability, clarity, completeness, computational efficiency, conciseness, consistency, and organizational fitness) and ontology aspects (vocabulary, syntax, structure, semantics, representation, and context). Building on the two large meta-properties of unity and simplicity, [2] have developed an evaluation methodology called OntoAbsolute that allows to assess the taxonomic and non-taxonomic relationships, analyzes the conceptual structure and evaluates the ontology as a whole.

3 Proposed evaluation method

Our method of analysis of the taxonomic consistency of ontologies is based on two key elements (1) the projection of the ontology to evaluate on WordNet, and (2) the checking of the conformity of its hierarchical links compared to those linking WordNet corresponding synsets.

WordNet is an on-line lexical database that lists, classifies and connects in various ways the semantic and lexical content of a number of languages such as English and French [18]. For each word of the language, WordNet offers a list of synsets (synonym set) that correspond to all its possible meanings. The synset is the building block upon which rests the entire system. It corresponds to a group of interchangeable words denoting one sense or a particular purpose. Different words and synsets are interconnected by a number of lexical relations as the hyponymy/hyperonymy, holonymy/meronymy and synonymy/antonymy. These relationships can be exploited to explore the exact meaning of a given word. Its third release [2] offers a number of 155287 words expressing 117659 different meanings (synset).

These values reveal the semantic richness of WordNet and enhances the utility of its use as a reference taxonomy in order to verify the structure of ontologies. However, its generic nature assign a special attention to the polysemy problems. Indeed, for a given concept identifier, WordNet has multiple possible nodes, each of which is part of a particular context and refers to a different signification. Consequently, the good location of a concept in WordNet returns to find the synset that reflects its exact meaning.

[2] http://wordnet.princeton.edu/wordnet/man/wnstats.7WN.html

3.1 Projection of ontology on WordNet

The aim of this step is to locate the concepts of our ontology in WordNet that serves as a reference support for the analysis and validation of the ontology taxonomic structure.

For doing this, we are led to find for each concept the corresponding WordNet synset. It is obvious that this treatment can not be limited to a simple term search of the concept identifier in WordNet. knowing that the same word can support multiple meanings. Therefore, to be able to map a given concept in WordNet, we need to distinguish, among all proposed synsets, the one that better corresponds. Our solution is to involve the context of the concept in its marking task in WordNet. The context of a concept is described by its identifier, labels, comments, neighborhood and properties.

The most appropriate synset for a given concept is the one that shares with it the maximum of knowledge in terms of neighborhood and textual descriptions.

Figure 1: Mapping between ontology concepts and WordNet synsets

Given the following:

$W(F, S)$ which defines the vocabulary admitted by WordNet corresponding to a set of pairs (F, S), where F is the form of a string on a finite alphabet and $S = \{s/F\}$ is the set of senses supported by F. s denotes an element of the set of meanings S (i.e. a synset).

Let the function $P(c, s_i)$ (Equation 1) defines the degree of knowledge sharing between the concept c and the synset s_i that denotes the synset number i of the identifier name of c. The relevant synset to a concept c must check this commitment:

$$s_k = relSyn(c) \Rightarrow P(c, s_k) > P(c, sj)\ \ \forall s_k \neq s_j \quad (1)$$

The function P is described by the following algorithm:

- $syn(c)$ a function that returns the synsets related to the identifier of the concept c.
- $lab(c)$ a function that returns the set of labels of the concept c.

- $com(c)$ a function that returns the comments associated with the concept c.
- $super(c)$ a function that returns the direct subsumer of the concept c.
- $w\_com(s)$ a function that returns the significant words included in the comments associated with the concept c.
- $w\_syn(s)$ a function that returns the set of synonyms words related to the synset s.
- $w\_gloss(s)$ a function that returns the significant words that compose the definition associated to the synset s.

  and

For extracting the relevant synset to the root concept of our ontology, we can proceed as follows :

- If the concept has a single synset in WordNet, it is then the corresponding synset.
- If the concept has labels, the sharing degree between it and a given synset is described by the intersection of their respective labels and synonyms.
- If the concept has comments, the sharing degree between it and a given synset is described by the intersection of their respective comments and definitions.
- Otherwise, the selection can be done manually (only for the root concept).

Input : c (a concept name identifier)
BEGIN
    if($\mid syn(c) \mid = 1$)
        $P = 1$
    else if ($\mid lab(c) \mid > 0$)
        $P = \mid lab(c) \cap w\_syn(s) \mid / \mid lab(c) \mid$
    else if ($\mid com(c) \mid > 0$)
        $P = \mid w\_com(c) \cap w\_gloss(s) \mid / \mid w\_com(c) \mid$
    else return -1 *(Cannot locate the root c in WordNet)*
END.

However, the identification of the corresponding synset for a given non-root concept c is based on the computation of the distance that separates this synset to that associated with the closest subsumer of c in the ontology to be evaluated. We assume that the relevant synset s_k to a given concept is the one that is connected with the smallest number of subsumption links; among other synsets s_i of the same concept; to the corresponding synset of its subsumer. In this situation, the degree of knowledge sharing is described by the formula 2.

$$P(c, s_i) = \frac{1}{distance(s_i, relSyn(super(c))} \qquad (2)$$

3.2 Validation of ontology taxonomic structure

Once the concepts of the ontology to be evaluated are mapped with the WordNet synsets, it is now possible to check the compatibility between the taxonomic structure of the ontology and that of corresponding synsets.

The hypothesis on which we base our assessment is that a given subsomption relationship between two concepts is considered valid only if their corresponding synsets are connected by the shortest hyperonymy path compared to those linking the synset of the subsuming concept to all synsets associated with the other concepts.

Several graph-theoretic measures can be used to calculate the proximity between two synsets in WordNet. They are mainly based on the number of edges that separate two nodes in a taxonomy. The most commonly used measures in literature are Rada [23], Leacock & Chodorow [14], Hirst & St-Onge [13] and Wu & Palmer [32]. Rada measure is considered as the most obvious way to evaluate the semantic similarity in a hierarchical ontology. It corresponds to the shortest path between two concepts in an ontology where only taxonomic links are considered, i.e. hyperonymy and hyponymy. Leacock & Chodorow measure is an extension of Rada which is in fact normalized by introducing a division by the maximum hierarchy depth of the involved concepts. Path measure adopts the same principle as the previous two measures by considering the inverse of the number of nodes along the shortest path between two nodes. As for Hirst & St-Onge measure, similarity between two concepts is determined by the minimum number of direction changes of the path between the two concepts. Indeed, depending on this measure, we distinguish four relation types between two concepts which are extra-strong, strong, medium and week. Wu & Palmer measure evaluates the similarity between two concepts as the distance of their most specific common subsumer to the root of the ontology divided by the shortest path between them.

4 Experimentation

In this section, we expose and interpret the results of applying our proposed evaluation method on a part of the ontology of AKTtiveSA[3]. This ontology deals with a number of geographical aspects of the knowledge infrastructure for humanitarian and disaster relief operations. It encompasses a wide variety of conceptualizations including terrain features, transport routes, rivers, shorelines, terrain elevation data, etc. [24]. The part to which we will limit our experimen-

[3]http://www.zaltys.net/ontology/AKTiveSAOntology.owl

tal study represents a hierarchy of 23 concepts modeling some Earth hydrographic objects (Table 2). Our scope of analysis will be restricted to concepts whose names appear in WordNet.

Figure 2: Taxonomic structure of the AKTiveSA ontology

As indicated above, the rapprochement between the concepts of the ontology to evaluate and the WordNet synsets may be supported by the texts associated with them, but also by their subsumers in both hierarchies. The concepts of our ontology lack any label. Table 1 shows the associated comments for each concept of the analyzed part.

Table 1: AKTiveSA concepts and relative comments

Concept	Comments
Body of water	Represents planetary structures that are part of the hydrosphere and that have a primary substance composition of a water.
Aquifer	An aquifer is an underground structure of water-bearing, permeable rock.
Reservoir	
Pond	A pond is a body of water smaller than a lake. However the difference between a pond and a lake is largely subjective. The term pond usually describes small bodies of water, generally smaller than one would require a boat to cross. Another definition is that a pond is a body of water where even its deepest areas are reached by sunlight.
Lake	A lake is a body of water surrounded by land.
Stream	A stream is a body of water with a detectable current, confined within a bed and banks. Stream is also an umbrella term used in the scientific community for all flowing natural waters.
River	A river is a large stream, which may also be a water way.
Canal	Canals are man-made waterways, usually connecting existing lakes, rivers, or oceans. Irrigation canals are man-made waterways for the delivery of water and preceded the use of transportation canals used by barges or narrowboats on smaller canals, and by ships on ship canals that connect to the ocean.
Creek	In British English and Indian English usage, a creek is a tidal water channel. Creeks may often dry to a muddy channel with little or no flow at low tide, but often with significant depth of water at high tide.
Spring	A spring is a point where groundwater flows out of the ground, and is thus where the aquifer surface meets the ground surface.
Ocean	A large body of water constituting a principal part of the hydrosphere.

The results of the evaluation of the structural proximity between each concept and each of its corresponding synsets are given in Table 2. For each of these concepts, we indicate the Path similarity between each of its related synsets and the synset that corresponds to its closest subsumer concept in the AKTiveSA ontology. The most relevant synset for a given concept is that having the highest Path similarity value (written in bold).

Table 2: The taxonomic proximity values between concepts and related synsets.

concept	#n#1	#n#2	#n#3	#n#4	#n#5	#n#6
Pond	**0.33**	-	-	-	-	-
Aquifer	**0.16**	-	-	-	-	-
Lake	**0.5**	0.11	0.11	-	-	-
Stream	**0.5**	0.09	0.08	0.11	0.08	-
Ocean	**0.5**	0.11	-	-	-	-
Reservoir	0.1	**0.5**	0.35	0.25	-	-
Canal	**0.25**	0.12	0.10	-	-	-
Creek	**0.5**	0.11	-	-	-	-
River	**0.5**	-	-	-	-	-
Spring	0.09	0.09	**0.14**	0.11	0.09	0.08

Excepting the case of the concept *Canal*, the confrontation of the results detailed in Table 2 with the definitions of the concepts (Table 1) and their relevant synsets (Table 4) proves the effectiveness of our approach to identify concepts in WordNet. We clearly notice that the definitions of the AKTiveSA concepts are highly compatible with the glosses related to found synsets. Furthermore, the localization of concepts in WordNet helps to better understand their contexts. The example in Table 3 reinforces this idea and shows that, among the three synsets related to the concept *Canal*, the first synset has the highest structural similarity compared to representative sysnets of the other concepts.

Table 3: The Path similarity between the synsets of *canal* and the other concept synsets

	b.water #n#1	aquifer #n#1	reservoir #n#2	pond #n#1	lake #n#1
canal#n#1	0.33	0.12	0.20	0.20	0.25
canal#n#2	0.14	0.10	0.11	0.11	0.12
canal#n#3	0.11	0.12	0.09	0.09	0.10

	stream #n#1	river #n#1	creek #n#1	spring #n#3	ocean #n#1
canal#n#1	0.25	0.20	0.20	0.12	0.25
canal#n#2	0.12	0.11	0.11	0.10	0.12
canal#n#3	0.10	0.09	0.09	0.12	0.10

On the other hand, by browsing through the glosses of the three synsets of *Canal*, it seems clearly that the definition "*long and narrow strip of water made for boats or for irrigation*" associated with the third synset is more appropriate to the context of geographic objects than the first synset. A simple computation of the terminological intersection between the concept comments and both associated synset glosses can reinforce this attitude and allows us to conclude that this definition is the closest to

the concept *Canal*. So, it is the third synset that will be considered rather than the first. However, this terminological likeness does not imply any semantic relatedness. Indeed, the calculation of the structural proximity between each of these two synsets and the other synsets related to ontology concepts (Table 3), shows us clearly that the synset number 1 is the closest of the ontology context and justifies the interest in favoring such measure to the terminological ones.

Applying our method of projection of the ontology on WordNet, the found correspondences (concept, synset) and related scores are described in Table 4. For each concept, we show the number of candidates WordNet synsets as well as the identifier and meaning of its relevant synset.

Table 4: The concepts of AKTiveSA ontology and their associated synset glosses

Concept	nb. syn.	Id Syn.	Gloss
Body of water	1	Body_of_water #n#1	the part of the earth's surface covered with water (such as a river or lake or ocean).
Aquifer	1	aquifer #n#1	underground bed or layer yielding ground water for wells and springs etc.
Reservoir	4	reservoir #n#2	lake used to store water for community use
Pond	1	pond #n#1	a small lake.
Lake	3	lake #n#1	a body of (usually fresh) water surrounded by land
Stream	5	stream #n#1	a natural body of running water flowing on or under the earth
River	1	river #n#1	a large natural stream of water (larger than a creek)
Canal	3	canal #n#1	an indistinct surface feature of Mars once thought to be a system of channels; they are now believed to be an optical illusion.
Creek	2	creek #n#1	a natural stream of water smaller than a river (and often a tributary of a river).
Spring	6	spring #n#3	a natural flow of ground water.
Ocean	2	ocean #n#1	a large body of water constituting a principal part of the hydrosphere.

Once the ontology concepts are located in WordNet, it is now possible to check the conformity of their hierarchical structure compared to that of the corresponding synsets. Table 5 shows; for each of the considered concepts; the corresponding synset and its nearest subsumer. A subsumption link for c_1 to c_2 (i.e. c_1 isA c_2) is considered valid only if the synset related to c_2 is the nearest subsumer to that of c_1 compared to synsets of all other concepts.

The six firsts lines of the Table 5 prove the accuracy of *isA* relationships for the pairs of concepts (Reservoir, Lake), (Lake, Body_Of_Water), (Stream, Body_Of_Water), (River, Stream), (Creek, Stream) and (Ocean, Body_Of_Water). Starting from the hypothesis that the used ontology is proven, these results confirm the interest of our taxonomic evaluation method.

Table 5: The found synsets and their most closer subsumers

Synset	Most closer subsumer	Path value
Reservoir#n#2	Lake#n#1	0.5
Lake#n#1	Body_Of_Water#n#1	0.5
Stream#n#1	Body_Of_Water#n#1	0.5
River#n#1	stream#n#1	0.5
Creek#n#1	stream#n#1	0.5
Ocean#n#1	Body_Of_Water#n#1	0.5
Pond#n#1	Lake#n#1	0.5
Canal#n#3	none	-
Aquifer#n#1	none	-
Spring#n#3	none	-

On another hand, the seventh line shows that the concept *Pond* can be considered a sub-concept of *Lake*. This can be very convincing if we admit that the *pond* is a small area of *still water*, especially one that is artificial[4].

The three last lines show that none of the concepts *Canal*, *Aquifer*, and *Spring* has a subsumer among all other concepts of the analyzed part. In fact, WordNet considers that *Canal* is a water course rather than body of water. On their part, the concepts *Aquifer*[5] and *Spring*[6] are seen as geological formation. This same meaning is shared by other dictionaries such as Oxford Dictionaries. These results are very useful in the sense that they can help us to revise and correct certain taxonomic relationships.

5 Conclusion

In this paper, we firstly presented a brief literature review of the main ontology evaluation methods with a special focus on the taxonomy aspects. We secondly present our method to check the hierarchical structure consistency of a given ontology. Our method is based on two main phases enabling respectively to (1) project the concepts of the ontology to evaluate on WordNet, and (2) to check the conformity of their hierarchical links compared to those linking WordNet corresponding synsets. To accomplish this task, we

[4] Oxford Dictionaries : http://www.oxforddictionaries.com/

[5] Oxford Dictionaries : Aquifer is "a layer of rock or soil that can absorb and hold water"

[6] Oxford Dictionaries : Spring is "a place where water comes naturally to the surface from under the ground"

have used the Path graph-theoretic measure that calculates the length of the shortest path between two given synsets in WordNet. The results of the experimentation that we have described in the last section show that the proposed method is promising.

As for further research directions, we envisage to incorporate this method in a quality driven building process that will allow us to use existing geographic objects ontological resources for the conceptual enrichment of a given core ontology dedicated to model satellite images content.

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